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硕士学位论文

# 长江口小黄鱼 (*Larimichthys polyactis*) 耳石形态及在生物学研究中的应用

Otolith Morphology of Small Yellow Croaker  
(*Larimichthys polyactis*) in Yangtze River Estuary and the  
Application in Biology Study

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## 摘要

耳石为硬骨鱼类内耳中的钙化结构，主要起到听觉及平衡鱼类身体的作用。目前耳石形态学已成为国内外鱼类学研究的热点，涉及鱼类年龄与生长、种群划分、群体识别、生活史反演等多个领域。本研究以长江口小黄鱼（*Larimichthys polyactis*）为研究对象，研究耳石形态与体长、体质量的关系，探讨耳石生长与小黄鱼特殊生长阶段的关系，且从生物学及耳石形态学角度综合探讨小黄鱼春季群体及秋季群体间的差异，并就耳石形态在两个不同生态群体间的识别作用及年龄鉴定作用进行初步探究，旨在丰富小黄鱼耳石形态学研究，为小黄鱼生活史研究、生态群体划分及渔业资源管理提供科学依据。主要研究结果如下：

（1）探讨线性函数、幂函数、指数函数与耳石最大半径、最小半径、长、宽及质量与体长、体质量关系，结果显示幂函数模拟效果最佳；且耳石最大半径及耳石长度与体长、体质量间的相关性较大（ $R^2=0.758\sim0.833$ ），同时发现在耳石相对尺寸中，最大半径及长度的变化趋势相对稳定。因此，在今后小黄鱼渔业资源评估中，利用耳石最大半径及耳石长度来推算小黄鱼体长及体质量更为合理。

（2）利用主成分分析法（PCA）得到耳石圆度（ $I_2$ ）、Ferret 比（ $I_9$ ）可以代表 10 个耳石形态指标并用于描述小黄鱼耳石形态特征。耳石圆度（ $I_2$ ）随体长的增加逐渐减小，Ferret 比（ $I_9$ ）随体长的增加逐渐增大，且减小和增大的趋势逐渐变缓。在体长为 110mm 和 160mm 时，耳石圆度（ $I_2$ ）分别出现减小速率变缓的拐点，Ferret 比（ $I_9$ ）分别出现增大速率变缓的拐点，这与小黄鱼的性成熟体长（108mm）及生长速率变缓的拐点体长（169.2mm）接近；同时，耳石相对厚度在性成熟体长和生长速率变缓的拐点体长之间存在快速增长的现象。推测耳石可有效地记录了小黄鱼性成熟时期及各生长阶段的变化。

（3）小黄鱼春季群体及秋季群体存在一定的差异，这种差异在生物学特征及耳石形态特征上都得到了体现：

生物学特征方面：5 月，小黄鱼春季群体的平均体长为  $135\pm14\text{mm}$ ，11 月秋季群体平均体长为  $128\pm15\text{mm}$ ，两个群体体长分布呈现极显著差异（ $t=5.688$ ， $P<0.01$ ）。年龄结构方面，春季群体以 1 龄鱼居多，推测春季群体中更多的性成熟个体进入长江口进行产卵生殖，而秋季群体中当年幼龄鱼所占比例较高。同时，两个群体的生长模式（ $F=119.645$ ， $P<0.01$ ）及肥满度（ $t=7.013$ ， $P=0.013<0.05$ ）

也存在一定差异。春季群体中, 小黄鱼的体长 (mm) - 体质量 (g) 关系式:  $W=3.459 \times 10^{-5} L^{2.835}$  ( $R^2=0.868$ ,  $n=303$ ), 属负异速生长模式, 肥满度较低; 秋季群体中, 体长 (mm) - 体质量 (g) 关系式为:  $W=1.964 \times 10^{-5} L^{2.975}$  ( $R^2=0.934$ ,  $n=327$ ), 属等速生长模式, 肥满度较高。

耳石形态学方面: 根据耳石外侧面瘤状突起的数量, 将耳石分为 I 型、II 型、III 型三种类型, 其中 I 型突起的数量大于 10, III 型耳石表面光滑无突起, II 型介于两者之间。不同群体间三种耳石形态类型分布频率出现明显差异, 春季群体中三种耳石类型分布较为均匀, I 型、II 型、III 型分布百分比分别为 23.43%、35.97%、40.60%; 秋季群体则主要以 I 型为主, 分布百分比达 83.23%; 且十个耳石形态指标经 T-test 检验后发现存在明显的群体差异。推测小黄鱼不同生态群体间的耳石形态差异与环境及个体差异有关。

(4) 利用耳石 10 个形态指标及 77 个傅里叶谐波值对小黄鱼两个不同生态群体 (春季群体和秋季群体) 进行判别分析。为消除体长及年龄对耳石形态的影响, 本研究选取两个生态群体中体长范围为 130mm~140mm 的 1 龄个体, 并对耳石形态指标进行对数 [ $\log (X+1.1)$ ] 转换。本研究发现, 单用耳石形态指标得到的判别成功率为 85.4% 和 81.7%, 单用傅里叶分析值得到的判别成功率为 84.8% 和 85.2%, 结合两种指标得到的判别成功率为 92.7% 和 91.3%。表明耳石形态可有效地识别不同小黄鱼生态群体, 且利用多种指标可提高群体识别成功率。

(5) 利用 Fisher 逐步判别法判别秋季群体中 0 龄、1 龄及 2 龄三个年龄群体, 发现只利用耳石形态指标及傅里叶谐波值进行判别时, 综合判别率成功率为 80.6%, 当加入耳石质量后, 综合判别成功率明显提高, 达到 87.3%。说明耳石质量在小黄鱼年龄鉴定中起到一定的作用。

**关键字:** 长江口; 小黄鱼; 耳石形态; 生活史; 群体识别; 年龄鉴定

## Abstract

The otolith is a calcified structure in the inner ear of teleost fishes, which processes the acoustic and postural information. Recently, the otolith morphology has become a research hotspot both in China and abroad, and the research areas are related to the age and growth、population division、group recognition、life history recovering and so on. This research studied the otolith morphology of small yellow croaker (*Larimichthys polyactis*) in order to demonstrate the relationship between otolith and the standard length and body weight of fish, and also revealed that the growth of otolith could effectively reflect the fish growth at different life stages; And we also discussed the biology and otolith morphology differences between spring group and autumn group of small yellow croaker; Finally, a preliminary study about the role of otolith in group identifying and age determination was carried out. The aim of this study is to enrich the area of otolith morphology of small yellow croaker and provide scientific basis for its life history exploration、group division and fishery resources management.

(1) Linear, power functional and exponential growth equations were used to describe the relationship between the growth of otolith and the fish growth. A significant power functional relationship was found between five otolith measurement index (maximum radius、minimum radius、length、width、weight) and the standard length、body length, especially for the maximum radius and the length of otolith ( $R^2=0.758\sim0.833$ ). In the meantime, the relative size of maximum radius and length of otolith varied stably. So, it is reasonable to infer growth conditions by using these two indexes in the following study.

(2) This study selected the otolith roundness ( $I_2$ ) and the Feret ratio ( $I_9$ ) by the Principal Component Analysis (PCA) to describe the otolith shape of small yellow croaker. The otolith roundness ( $I_2$ ) had a negative relationship with fish standard length, while the relationship between the Feret ration ( $I_9$ ) and standard length was positive. Otolith roundness ( $I_2$ ) appeared two inflection points of dropping slowly and Feret ration ( $I_9$ ) appeared two inflection points of rising slowly when the standard

length was 110mm and 160mm, which is corresponding to the first maturity size (108mm) and the inflection point of slow growth rate (169.2mm), respectively. In addition, the relative thickness of the otolith increased rapidly between these two points. So, otolith may record the phase of sexual maturity and the growth change at every life stage of small yellow croaker.

(3) The differences between the spring group and the autumn group were significant and was reflected in both biological and otolith morphological characteristics:

Biological characteristics: the average standard length of spring group and autumn group was  $135 \pm 14$ mm and  $128 \pm 15$ mm, respectively, and the difference was significant ( $t=5.688$ ,  $P<0.01$ ). The spring group was dominated by one-year-old individuals, inferring that mature fish migrated to Yangtze River Estuary to spawn, and the autumn group was mainly composed by juvenile fish. The growth pattern ( $F=119.645$ ,  $P<0.01$ ) and condition factor ( $t=7.013$ ,  $P=0.013<0.05$ ) also presented significant difference between the two groups. In the spring group, the relationship between standard length (mm) and body weight (g) could be described as  $W=3.459 \times 10^{-5} L^{2.835}$  ( $R^2=0.868$ ,  $n=303$ ), which belonged to the type of negative constant growth, and the average condition factor is lower than the autumn group. In the autumn group, the relationship was  $W=1.964 \times 10^{-5} L^{2.975}$  ( $R^2=0.934$ ,  $n=327$ ), which belonged to the type of constant growth.

Otolith morphological characteristics: three types of otolith were classified based on the number of strumae on the lateral surface. The type I was defined when the number of strumae was more than 10, the type III was defined when the lateral surface was smooth, and the characteristics of type II fell in between. In spring group, the distribution of three otolith morphology types was relatively equal, accounting for 23.43% (type I)、35.97% (type II) and 40.59% (type III), respectively. While, in autumn group, the type I is the dominant one, accounting for 83.23%. In addition, all these 10 shape indexes appeared significant difference between these two groups by the T-test. It is supposed that various shapes of otoliths may attribute to the variation of environment condition and individual differences.

(4) 10 shape indexes and 77 Fourier coefficients were used to discriminate the spring group and autumn group of small yellow croaker. In order to remove the length and age effects on otolith shape analysis, the samples whose standard length varied from 130mm to 140mm and age restricted one-year-old were chosen in this study, and we also did  $[\log (X+1.1)]$  transformation to the otolith shape indexes. The results of discriminant analysis showed that the correct classification ratio in these two groups was 85.4% and 81.7% by only using 10 shape indexes, and were 84.8% and 85.2% by only using the Fourier coefficients. If combining both kinds of variables, the correct classification ratio in these two groups would reach up to 92.7% and 91.3%. The results showed that otolith morphology could effectively discriminate different groups of the small yellow croaker and multiple indexes could improve the ability of otolith morphology analysis obviously.

(5) Fisher stepwise discrimination criterion was applied to discriminate a series of 0, 1, 2 age groups. The results showed that the correct classification ratio was 80.6% and a higher score (87.3%) was got when synthesizing the otolith weight. It supported that otolith weight is an effective way to identify the age of small yellow croaker.

**Key words:** Yangtze River Estuary; small yellow croaker (*Larimichthys polyactis*); otolith morphology; life history; group recognition; age determination



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## 第一章 绪论

### 1.1 耳石形态在鱼类生物学中的应用

耳石是硬骨鱼类内耳膜迷路内的结石,主要成分为碳酸钙,起到声音接收及平衡身体的作用。鱼类耳石分为矢耳石、星耳石和微耳石三种,其中星耳石和微耳石较小,而矢耳石较大,易于观察,一般作为耳石研究的首选材料(Campana, 1993)。耳石会在鱼类生长发育过程中持续生长,其形态特征较为稳定,具有高度的物种特异性和群体特异性,已被广泛应用于鱼类物种鉴定和群体识别,近年来逐步形成一个独特的研究领域,在过去十年内举行的三次国际鱼类耳石学术会议更是大大推进了耳石形态学研究的发展。

#### 1.1.1 年龄鉴定

自 1899 年 Reibisch 第一次观察到耳石年轮以来,耳石就被广泛地应用于鱼类年龄鉴定当中。Campana 和 Thorrold (2001)统计了 1999 年全球范围内判读近 100 万尾鱼的年龄所用鉴定材料,发现绝大部分为用鳞片和耳石。

传统的鱼类年龄鉴定方法是将耳石磨片进行轮纹判读,然而此种方法较为主观,存在很大的人工判读误差,同时,当样本量较大时,耳石切片的打磨制备就需消耗大量的人力和时间,利用耳石形态学进行年龄鉴定则可有效地避免此类误差,提高实验效率。Boehlert (1985)通过多元回归分析发现裂吻平鲈(*Sebastes diploproa*)的年龄可通过耳石形态,尤其是耳石质量估算得到;Cardinale 等(2000)发现利用耳石质量可有效地判读大西洋鳕(*Gadus morhua*)和欧洲鳎(*Pleuronectes platessa*)的年龄,耳石质量与年龄存在显著相关性;沈建忠等(2002)认为洪湖鲫(*Carassius auratus*)的耳石质量与年龄的相关性极显著,利用耳石轮纹判读的年龄与利用“耳石质量-年龄”关系推算的年龄之间并无差异;张弛(2012)仅利用耳石形态指标对 0~2 龄皮氏叫姑(*Johnius belangerii*)个体进行年龄判别,得到综合判别成功率为 64.1%,当加入耳石质量后,综合判别成功率上升至 93.5%。可见,利用耳石质量进行鱼类年龄鉴定在日后的渔业资源评估研究中具有广泛的应用前景。

### 1.1.2 物种鉴定

鱼类耳石的形态结构较为稳定,且因遗传因子的影响表现出高度的种间特异性,自 1884 年德国古生物学家 Koken 首次利用矢耳石形态进行鱼种鉴定开始,耳石形态在鱼类物种鉴定中的作用就得到了广泛重视。Stransky (2005) 利用耳石形态的椭圆傅立叶分析法判别了北大西洋平鲉属 (*Sebastes*) 的两个种,总体判别成功率均高达 70%;张国华等 (1999) 利用耳石形态的测量性状对 6 种鲤科鱼类进行判别分析,其中 5 种鱼的判别率达到 100%;张晓霞 (2010) 运用耳石形态指标及傅里叶谐波值成功判别了刀鲚、湖鲚、凤鲚三个不同种,判别成功率分别 92.9%、92.8%、96.0%。众多的研究都表明,耳石形态是鱼类物种鉴定的有效材料。

### 1.1.3 群体识别

同种鱼类的不同群体由于受外界环境因子的影响,生长发育常常存在显著性差异,进而影响耳石的沉积,形成群系特异性。Stransky 等 (2008) 对地中海及东北大西洋区的竹荚鱼 (*Trachurus trachurus*) 群体进行耳石形态学分析,发现利用耳石形态可以有效地区分竹荚鱼的三个群体,判别率为 88%~91%;王英俊等 (2007) 利用耳石形态分析发现吕泗群体与赣榆群体、胶南群体的欧氏距离为 3.38 和 3.09,而胶南群体与赣榆群体的欧氏距离达到了 4.59,三个群体存在一定的差异。

然而,耳石形态会因性别 (陆化杰等, 2011)、生长 (Lombarte 和 Lleonart, 1993)、年龄 (Campana 和 Casselman, 1993) 的影响在种内个体间形成较大差异,给群体识别带来一定的影响。所以当鱼体样本中体长或年龄差异足够大时,消除体长组别或年龄组别间的耳石形态差异是必不可少的。

### 1.1.4 生活史及生态类型研究

生理或环境的胁迫会对鱼体生长节律带来一定的影响,从而在耳石形态方面 (如轮纹的宽度、清晰度、颜色深浅、耳石外轮廓、长短轴比例等) 表现出与正常个体存在一定的特殊差异,从而有效地记录鱼类在生长和发育过程中所经历的



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